

# Calibration method for electrode gains in an axially symmetric stripline BPM\*

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The four electrodes in the stripline beam position monitor (BPM) for Hefei Light Source (HLS II) storage ring are of axially symmetric type. We have derived a new calibration method of electrode gains for this type stripline BPM. The gain fit error of different data grids was analyzed, and the  $\pm 5$  mm by  $\pm 5$  mm grid is the best. The electrode gains of two stripline BPMs (HLS II SR-BD-STLB1 and HLS II SR-BD-STLB2) were obtained based on offline calibrated data. The results show that data after fitting gains are improved, with the electrode gains being between 0.94 and 1.15.

Keywords: Stripline beam position monitor, Electrode gain, Axially symmetric, Calibration

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## I. INTRODUCTION

The Hefei Light Source (HLS) is being upgraded to HLS II. Three stripline BPMs are designed to measure the beam position, emittance and momentum dispersion in the storage ring. To decrease beam emittance, the circular vacuum chamber of the storage ring will be changed to an octagonal type. A cross-section of the stripline BPM is shown in Fig. 1 (in mm). Due to mechanical errors of the stripline BPM, the four axially symmetric electrodes, labeled with #R, #L, #T and #B to denote the horizontal (left and right) and vertical (top and bottom) electrodes, do not have the same relative gain. The differences in electrode gain will couple the measured horizontal position with the vertical position, resulting in measurement errors [1]. To measure beam parameters correctly, the electrode gains of a stripline BPM shall be measured.

Electrode gain for button BPM was measured by Rubin *et al.* [1]. This method requires mirror symmetry geometry of the four BPM electrodes. Geometry of the four BPM electrodes can be mirroring symmetric or axially symmetric. The measurement method of electrode gains for stripline BPM of the mirroring symmetric type is the same as the method for button BPMs. The geometry of BPM electrodes on the HLS II storage ring is axially symmetric, and an offline measurement method is developed to measure the electrode gains, which uses three electrode gains and a correction factor.

## II. METHODS

The quadrupole component with difference/sum method for the stripline BPM can be expressed as Eq. (1):

$$Q_{\Delta/\Sigma} = \frac{V_R + V_L - V_T - V_B}{V_R + V_L + V_T + V_B}, \quad (1)$$

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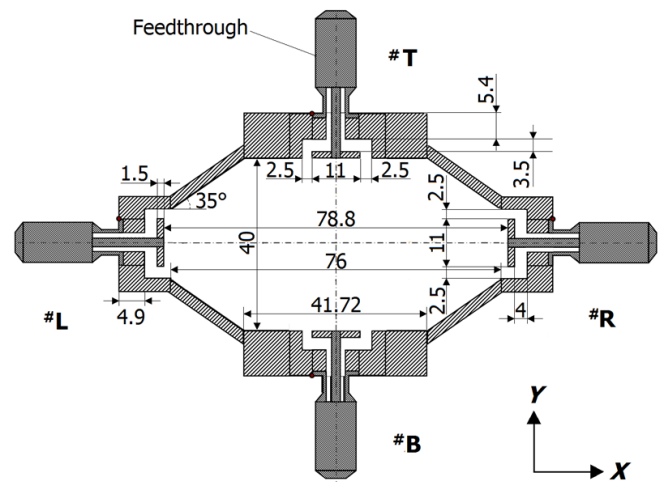


Fig. 1. The cross-section of the stripline BPM for the HLS II storage ring.

where  $V_R$ ,  $V_L$ ,  $V_T$  and  $V_B$  are electrode signals for the four electrodes. Assuming that the #R, #L, #T and #B electrodes are in  $X$  and  $Y$  axis, as shown in Fig. 1, and ignoring the higher order components, the quadrupole component for stripline BPM of axially symmetric type for circular vacuum chamber [2, 3] can be calculated by Eq. (2):

$$Q_{\Delta/\Sigma} = S_Q (x_0^2 - y_0^2 + \sigma_x^2 - \sigma_y^2), \quad (2)$$

where  $(x_0, y_0)$  is the beam position in the BPM,  $(\sigma_x, \sigma_y)$  is the beam transverse size, and  $S_Q$  is the quadrupole component sensitivity, which is relevant to azimuthal opening angle of the electrodes and distance from electrode to the BPM center.

For a stripline BPM of the axially symmetric type on an octagonal vacuum chamber, the boundary element method [4] and gaussian weighted method of 2D-grid structure [5] are used to simulate beam moving in the BPM. The model for stripline BPMs in the HLS II storage ring was established based on the boundary element method using Matlab.

The quadrupole component  $Q_{\Delta/\Sigma}$  for the stripline BPM

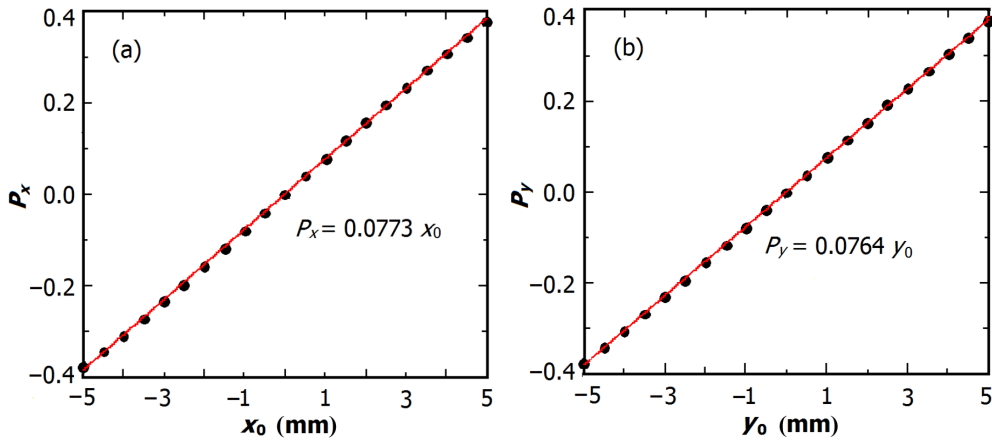


Fig. 2. (Color online) Horizontal (a) and vertical (b) sensitivities using the difference/sum method.

on the HLS II storage ring can be calculated as:

$$Q_{\Delta/\Sigma} = Q_0 + S_Q (x_0^2 - y_0^2 + \sigma_x^2 - \sigma_y^2). \quad (3)$$

As the distance between horizontal electrodes differs from that between vertical electrodes, there exists a non-zero component  $Q_0$ , compared to the stripline BPM on a circular vacuum chamber.

Ignoring the higher order components, the electrical position ( $P_x$ ,  $P_y$ ) can be obtained using the difference/sum method:

$$\begin{aligned} P_x &= (V_R - V_L)/(V_R + V_L) = S_x x_0, \\ P_y &= (V_T - V_B)/(V_T + V_B) = S_y y_0. \end{aligned} \quad (4)$$

Combining Eqs. (3) and (4) to eliminate  $x_0$  and  $y_0$ , we can obtain an expression that relates the electrode signals and beam transverse size:

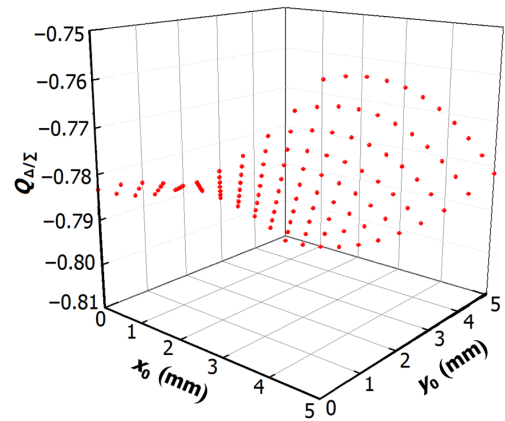
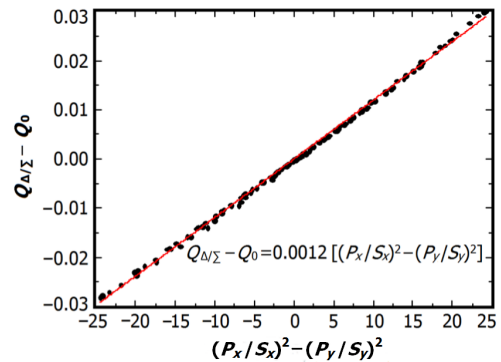
$$Q_{\Delta/\Sigma} - Q_0 = S_Q [(P_x/S_x)^2 - (P_y/S_y)^2 + \sigma_x^2 - \sigma_y^2]. \quad (5)$$

By using point charge to substitute gaussian beam, ( $\sigma_x$ ,  $\sigma_y$ ) becomes (0, 0), and Eq. (5) changes to:

$$Q_{\Delta/\Sigma} - Q_0 = S_Q [(P_x/S_x)^2 - (P_y/S_y)^2]. \quad (6)$$

HLS is being upgraded, so the electrode gains can be measured offline, rather than online. Two stripline BPMs (HLS II SR-BD-STLB1 and HLS II SR-BD-STLB2) were calibrated [6] by using antenna method, with an antenna of 0.2-mm tungsten filament. This situation can be regarded as that the beam passes the stripline BPM with ( $\sigma_x$ ,  $\sigma_y$ ) being (0.2 mm, 0.2 mm) and  $\sigma_x^2 - \sigma_y^2 = 0$ , so the electrode gains can be calculated using Eq. (6).

Before measuring the electrode gains, the parameters ( $S_x$ ,  $S_y$ ,  $Q_0$ ,  $S_Q$ ) shall be calculated. The boundary element method [4] was used to simulate a point charge moving in a grid of  $\pm 5$  mm by  $\pm 5$  mm with a 0.5 mm step. The four electrode signals of  $V_R$ ,  $V_L$ ,  $V_T$  and  $V_B$  were obtained to calculate the beam positions (Fig. 2) using Eq. (4). The position sensitivities ( $S_x$  and  $S_y$ ) can be obtained by fitting the

Fig. 3. (Color online) Simulated  $Q_{\Delta/\Sigma}$  as functions of  $x_0$  and  $y_0$ .Fig. 4. (Color online) Simulation and fitting of  $(Q_{\Delta/\Sigma} - Q_0)$  vs.  $[(P_x/S_x)^2 - (P_y/S_y)^2]$ .

simulation data. As shown in Fig. 2,  $S_x = 0.0773$  mm and  $S_y = 0.0764$  mm. The quadrupole component ( $Q_{\Delta/\Sigma}$ ) calculated using Eq. (1) at the point charge position ( $x_0$ ,  $y_0$ ) from (0, 0) to (5, 5) only, due to symmetry, is shown in Fig. 3. By plotting and fitting the data of  $(Q_{\Delta/\Sigma} - Q_0)$  vs.  $[(P_x/S_x)^2 - (P_y/S_y)^2]$  for  $Q_{\Delta/\Sigma}$  at ( $x$ ,  $y$ ) from (-5,

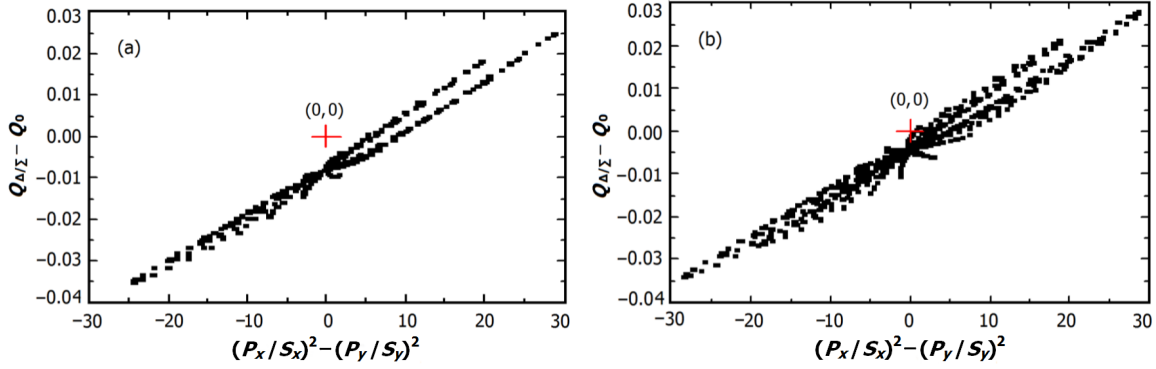


Fig. 5. (Color online)  $(Q_{\Delta/\Sigma} - Q_0)$  vs.  $[(P_x/S_x)^2 - (P_y/S_y)^2]$ , (a) simulated with 8% signal reduction of electrode #R, (b) calibrated on HLS II SR-BD-STLB1.

−5) to (5, 5), the parameters of  $Q_0$  and  $S_Q$  can be obtained using Eq. (6). Since electrode gains would be offline measured based on Eq. (6), in order to directly obtain constraints on the four electrode signals and decrease calculation error,  $(x_0^2 - y_0^2)$  should be replaced by  $[(P_x/S_x)^2 - (P_y/S_y)^2]$ . As shown in Fig. 4,  $(Q_{\Delta/\Sigma} - Q_0)$  varies linearly with  $[(P_x/S_x)^2 - (P_y/S_y)^2]$ , and  $Q_0 = -0.7832$  and  $S_Q = 0.0012 \text{ mm}^{-2}$  by the fitting data.

### III. GAIN ERROR OF THE BPM ELECTRODES

In practice, due to mechanical errors of stripline BPM, the four electrodes do not have the same gain, hence the failure of the connection between electrodes defined by Eq. (6). The

effect of gain errors was simulated by an 8% reduction of the signal on electrode #R. Fig. 5(a) shows  $(Q_{\Delta/\Sigma} - Q_0)$  vs  $[(P_x/S_x)^2 - (P_y/S_y)^2]$  under this condition for  $\pm 5 \text{ mm}$  by  $\pm 5 \text{ mm}$  grid simulated data. The relationship between  $(Q_{\Delta/\Sigma} - Q_0)$  and  $[(P_x/S_x)^2 - (P_y/S_y)^2]$  is no longer linear, deviating from zero (marked by the + sign). The BPM(HLS II SR-BD-STLB1) was calibrated offline [6]. The results are shown in Fig. 5(b). The situation is similar to Fig. 5(a). Therefore, the four electrodes of this BPM have different gains.

Due to the gain error of the four electrodes of the BPM, Eq. (6) cannot be applicable. So, a nonlinear least square fitting method was used to get the electrode gains ( $g_R$ ,  $g_L$ ,  $g_T$  and  $g_B$ ). The merit function is

$$\chi^2 = \sum_{i=1}^n \left\{ \left( \frac{g_R V_R^i + g_L V_L^i - g_T V_T^i - g_B V_B^i}{g_R V_R^i + g_L V_L^i + g_T V_T^i + g_B V_B^i} - Q_0 \right) - c \cdot S_Q \cdot \left[ \left( \frac{1}{S_x} \frac{g_R V_R^i - g_L V_L^i}{g_R V_R^i + g_L V_L^i} \right)^2 - \left( \frac{1}{S_y} \frac{g_T V_T^i - g_B V_B^i}{g_T V_T^i + g_B V_B^i} \right)^2 \right] \right\}, \quad (7)$$

where  $c$  is a coefficient to correct  $S_Q$ .

The best fit gains ( $g_R$ ,  $g_L$ ,  $g_T$  and  $g_B$ ) and  $c$  are obtained at a minimized  $\chi^2$ . The method was used by Rubin *et al.* [1], and they got their desirable results by controlling the gain equals to 1 every time for each of the #R, #L, #T and #B electrodes, and averaging the data from the fitting measurement. They found also that different grid data affected the gain fit algorithm. So, gain fit error was analyzed with different grids. Fig. 6 shows that gain fit error for three different grids, with 1%–12% reduction of the electrode signal. For each fit, the relative difference of the fitted gains from the real gains was calculated by  $\Delta g = (|g_{\text{fitted}} - g_{\text{real}}|/g_{\text{real}}) \times 100\%$ . From Fig. 6, the difference in data grid size affected the gain fit algorithm. The  $\pm 3 \text{ mm}$  by  $\pm 3 \text{ mm}$  grid is too small in size, hence the biggest gain fit errors, while the  $\pm 8 \text{ mm}$  by  $\pm 8 \text{ mm}$  grid is too big to ignore the higher order components and to justify Eqs. (3) and (4), which can be satisfied only in certain range

of the stripline BPM. We found that of all the data grids, the  $\pm 5 \text{ mm}$  by  $\pm 5 \text{ mm}$  grid has the least gain fit error, so it was chosen to measure electrode gains.

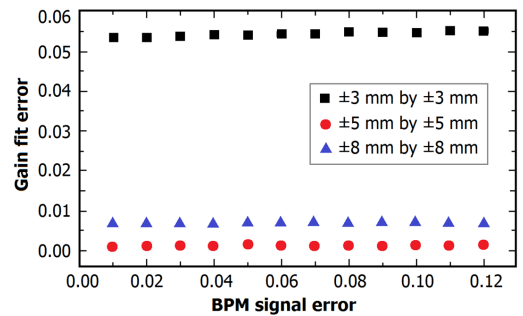


Fig. 6. (Color online) Simulation of gain fit error vs. BPM signal error for three data grids of different sizes.

#### IV. RESULTS OF CALIBRATION

Two BPMs, HLS II SR-BD-STLB1 and HLS II SR-BD-STLB2, were calibrated offline [6]. The beam was simulated by using 0.2 mm tungsten filament. The filament relative to the BPM was moved by stepper motor in a  $\pm 5$  mm by  $\pm 5$  mm grid, the data was acquired by Libera Brilliance [7]. The fitting results for HLS II SR-BD-STLB1 are given in Fig. 7, which shows that the data points after gain fitting are linear and pass through zero (0, 0). Fitted gains for the two BPMs are shown in Fig. 8, where the electrode gains are between 0.94 and 1.15.

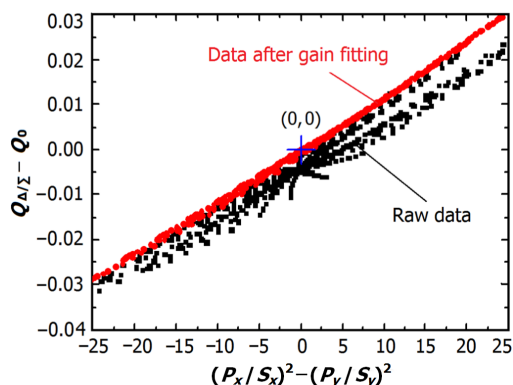


Fig. 7. (Color online)  $(Q_{\Delta/\Sigma} - Q_0)$  vs.  $[(P_x/S_x)^2 - (P_y/S_y)^2]$  for offline raw data and data after gain fitting of HLS II SR-BD-STLB1.

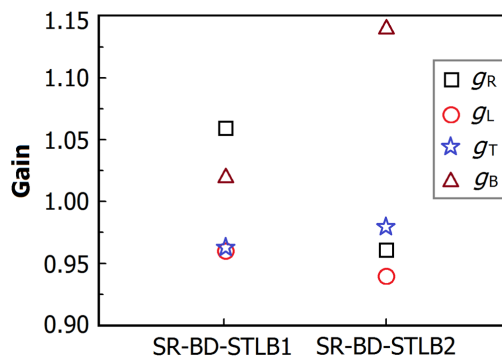


Fig. 8. (Color online) Fitted gains from offline calibrated data for the BPMs of HLS II SR-BD-STLB1 and HLS II SR-BD-STLB2.

#### V. CONCLUSION

We have derived offline measurement method of electrode gains for axially symmetric type stripline BPM. The simulation results show that fitted electrode gain error is the least in a  $\pm 5$  mm by  $\pm 5$  mm grid,  $(Q_{\Delta/\Sigma} - Q_0)$  vs  $[(P_x/S_x)^2 - (P_y/S_y)^2]$  curve after gain fitting is linear and passes through zero. In the future, online measurement of the electrode gains will be performed and the results be compared with the offline results.

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